Fermi National Accelerator Laboratory

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CDF and D0

Search for Particles Beyond the Standard Model at CDF and D0

Presented by J.M. Benlloch
For the CDF and D0 Collaborations

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ABSTRACT

We present the current mass limits for the existence of different particles that are predicted by physics beyond the Standard Model, in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, from the CDF and D0 experiments at Fermilab.

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1. Introduction

We report here on the searches for new particles beyond the standard model performed by the CDF [1] and D0 [2] detectors at Fermilab, from $p\bar{p}$ collisions at $\sqrt{s} = 1.8\ TeV$. During Run Ia (1992-93) CDF collected about 19 pb^{-1} and D0 15 pb^{-1}. In some cases, we present the results obtained with run Ia data and part of the ongoing run Ib (run Ia + run Ib represents a total of about 70 pb^{-1} at CDF and 50 pb^{-1} at D0). In most cases the analysis was performed by both experiments but we report here only on the one with the best current limit.

2. Search for SUSY particles

2.1. Search for squark and gluinos (D0, Run Ia)

Squarks and gluinos decay through a cascade of charginos and neutralinos. The signal would have multiple jets and significant missing transverse energy ($\not{E}_T$), arising from the escape of the weakly interacting, stable, lightest super symmetric particle (LSP) at the end of the decay chains. The 14 events seen and their distribution in $\not{E}_T$ is well predicted by the estimated background in lepton + jets ($17.1 \pm 1.8 \pm 6.8$ events). The mass limit contour in the squark-gluino mass plane is shown [3] in figure 1**a** for SUGRA inspired MSSM's, with the following sets of parameters: $tan(\beta) = 2.0$, $\mu = -250\ GeV/c^2$, $m_{H^+} = 500\ GeV/c^2$, $m_{top} = 140\ GeV/c^2$. Squarks and gluinos are excluded for masses less than $m < 212\ GeV/c^2$ for $m_{squark} = m_{gluino}$ and $m_{squark} < 144\ GeV/c^2$ for $m_{squark} >> m_{gluino}$ at the 95% CL.

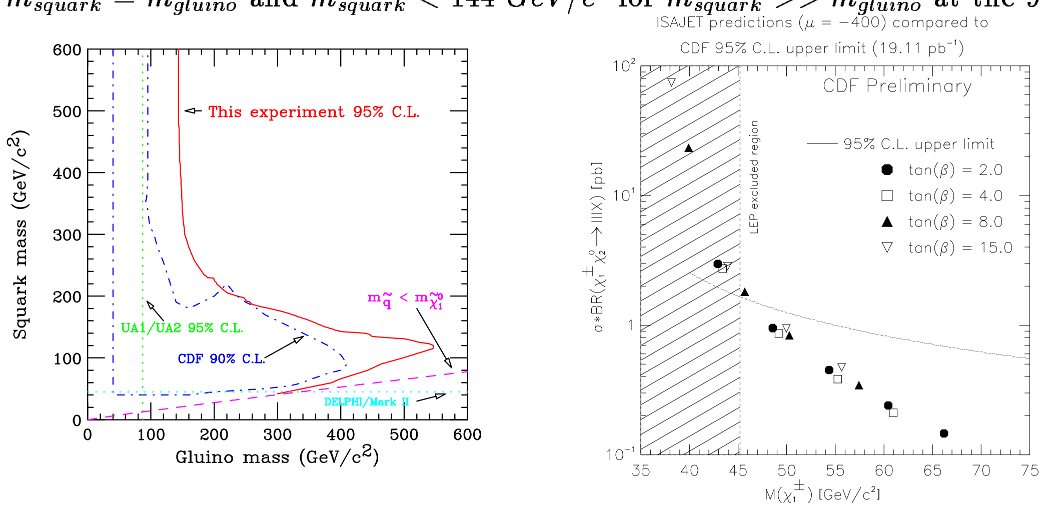

Figure 1: **a)** Squark versus gluino mass space showing regions excluded at 95% CL (confidence level) as well as the 90% CL limit curve from the previous 88-89 CDF analysis. **b)** 95% CL upper limit on $\sigma BR(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3lX)$ versus $M(\tilde{\chi}_1^{\pm})$. The data points are predictions of ISAJET. Note that $3l$ does NOT refer to the sum of all four modes, but rather any of them individually. The shaded region corresponds to the LEP limit.

2.2. Search for Charginos and Neutralinos (CDF, Run Ia)

Trilepton events are one of the most promising channels for the discovery of SUSY at a hadron collider. Chargino-neutralino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) pairs are produced via s-channel virtual W's or virtual squark exchange (t-channel), with subsequent leptonic decays ($\tilde{\chi}_1^{\pm} \to l\nu\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0$). The striking signature of these events is thus three isolated leptons, with minimal jet activity. The principal backgrounds are from Drell-Yan, Z, diboson, and $b\bar{b}$ events. The total background yield expected in run Ia data is 0.75 events, consistent with our observation of zero events. Charginos with mass less than 46 GeV/c^2 are excluded at the 95% CL (figure 1**b**).

3. Search for New Gauge Bosons

3.1. Z' Search (CDF, Run Ia and Run Ib)

Z' bosons are expected in most extensions of the standard model. These models typically specify the strengths of the couplings of such bosons to quarks and leptons but make no mass predictions.

The Z' search [4] required two isolated electrons or muons with $E_T > 25 GeV$. The invariant mass distribution with run Ia and run Ib data for both electrons and muons is shown in figure 2**a**. At large M_{ee} the dominant background is from Drell-Yan process. The distributions are fit to the standard model predictions plus a Z' mass resonance at higher mass. Mass limits are derived assuming standard model couplings and the Z' width is set equal to the Z width scaled by a factor $\frac{M_{Z'}}{M_Z}$. Z's with mass less than 650 GeV/c^2 are excluded at the 95% CL. There is a $Z' \to ee$ candidate with invariant mass of 510 GeV/c^2.

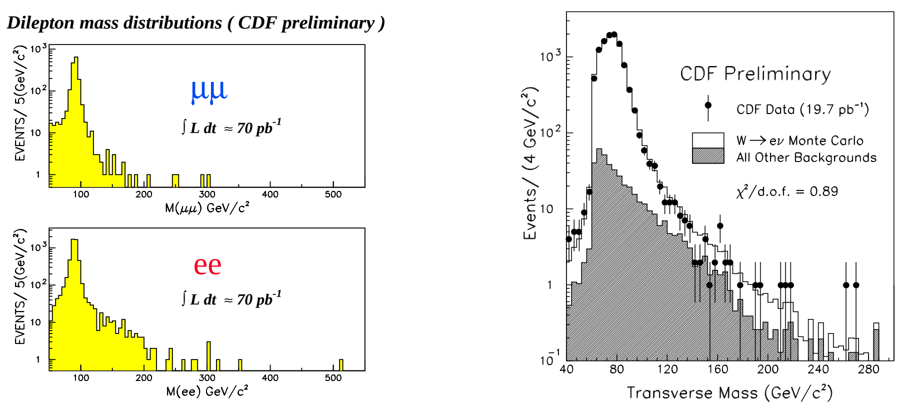

Figure 2: **a)** The invariant mass distribution for electron pairs candidates and muon pairs candidates in run Ia and run Ib. **b)** The transverse mass distribution for electron and neutrino candidates in run Ia.

3.2. W' Search (CDF, Run Ia)

Various extensions of the standard model predict an additional W boson. In left-handed models, such a W' is essentially a heavy version of the standard W boson. If it is heavy enough, it would decay predominantly to WZ pairs. In left-right symmetric models, the W' would decay to $e_R\nu_R$. Detection of such decay mode is complicated by the unknown properties of the ν_R. Here we assume that the ν_R is massless and stable.

The W' search required one isolated central electron with $E_T > 30\ GeV$ and missing transverse energy $\not{E}_T > 30\ GeV$ (corresponding to the neutrino). The transverse mass distribution with run Ia data [5] is shown in figure 2**b**. This distribution is fit to the standard model prediction plus a W' resonance at higher mass. W's with mass less than 652 GeV/c^2 are excluded at the 95% CL. Preliminary data from Run Ib contain a $W' \to e\nu$ candidate with uncorrected transverse mass of 420 GeV/c^2.

4. Search for Leptoquarks

Leptoquarks [6] are hypothetical color-triplet bosons appearing in many extensions of the standard model (GUTs, compositeness, technicolor). Leptoquarks carry both baryon and lepton quantum numbers, $\pm\frac{1}{3}$ and ± 1, respectively. Other quantum numbers are model dependent. At the Tevatron, leptoquarks would be produced in pairs. A leptoquark decays directly to a quark-lepton pair of the corresponding generation with branching ratio β or to a quark-neutrino pair with branching ratio $(1-\beta)$. It is assumed that there are the same number of leptoquarks as of lepton and quark generations. At a $p\bar{p}$ collider, this search is virtually independent of the unknown leptoquark coupling to leptons and (uud), and is thus quite orthogonal to searches at HERA.

4.1. First Generation Leptoquarks (D0, Run Ia)

The search for first generation leptoquarks involves two experimental signatures [7]: 2 electrons ($E_T > 25\ GeV$, removing the Z candidates $81 \leq M_{\mu\mu} \leq 101\ GeV/c^2$) and 2 jets ($E_T > 25\ GeV$), or 1 electron ($E_T > 20\ GeV$), missing E_T ($\not\!\!E_T > 40\ GeV$, removing the W candidates $M_T^{e\nu} > 105\ GeV/c^2$) and 2 jets ($E_T > 20\ GeV$). No events remain after all cuts.

The backgrounds from vector bosons + jets are almost completely eliminated by the cuts, and the remaining backgrounds from continuum lepton production and jet misidentification are small. The leptoquark mass limit versus the leptoquark branching fraction into electrons is shown in figure 3**a**. 1st generation leptoquarks with mass less than $M_{LQ_1} < 130\ GeV/c^2$ for $\beta = 1$ and $M_{LQ_1} < 116\ GeV/c^2$ for $\beta = 0.5$ are excluded at the 95% CL.

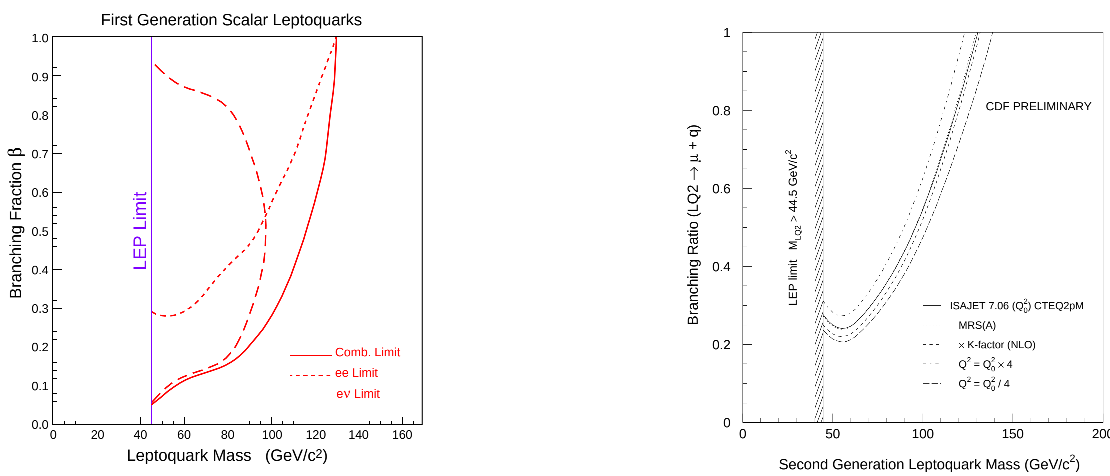

Figure 3: 95% CL lower limits on β as a function of the leptoquark mass for: **a)** The first generation leptoquarks (D0). **b)** The second generation leptoquarks (CDF).

4.2. Second Generation Leptoquarks (CDF, Run Ia)

Two isolated central muons are required [8] with $P_T > 20\ Gev/c$, opposite sign, azimuthal separation $\Delta\phi < 160^o$, and Z candidates ($75 \leq M_{\mu\mu} \leq 105\ GeV/c^2$) are removed. Two jets are also required with $E_T > 20 GeV/c^2$. There are two leptoquark candidate events, in good agreement with background expectations of 1.35 ± 0.5 events. 2nd generation leptoquarks with mass less than $M_{LQ_2} < 133\ GeV/c^2$ for $\beta = 1$ and $M_{LQ_2} < 98\ GeV/c^2$ for $\beta = 0.5$ are excluded at the 95% CL (figure 3**b**).

5. Dijet Mass Search (CDF, Run Ia and Run Ib)

The invariant mass spectrum between the two leading jets in the event from jet trigger data can be used to test QCD as well as to search for new mass resonances. The dijet mass spectrum extends from 150 to 1040 GeV (figure 4**a**). To search for new particles the mass spectrum is fit with a simple smooth parameterization and a search for bumps is performed. On a linear scale (figure 4**b**) we observe bumps which are fit by resonances at 200 GeV (2.4σ), 550 GeV (2.6σ), and 850 GeV (1σ). The angular distribution of the 550 GeV bump is compatible with QCD, although it is fit optimally by QCD + 5% signal (flat), which is the same amount of signal as predicted by the mass fit. The angular distribution of a bump-free region (400-500 GeV) is better fit by QCD alone, although it also prefers a fit with QCD + 3% signal. There is currently insufficient evidence to claim a signal. A previously reported CDF resonance search [9] using run Ia data alone found similar result. The 95% CL upper limits on signal cross section are compared to lowest order models of new particle production using CTEQ2L parton distributions (figure 4**c**). Excluded mass regions are determined when the model's cross section is higher than the measured upper limit. This preliminary search excludes at 95% CL models of [10]: axigluons for $200 < M < 1000\ GeV$, excited quarks for $200 < M < 600\ GeV$, Technirhos for $270 < M < 510\ GeV$, W' for $380 < M < 470\ GeV$, Z' for $410 < M < 460\ GeV$ and E6 diquarks for $370 < M < 460\ GeV$.

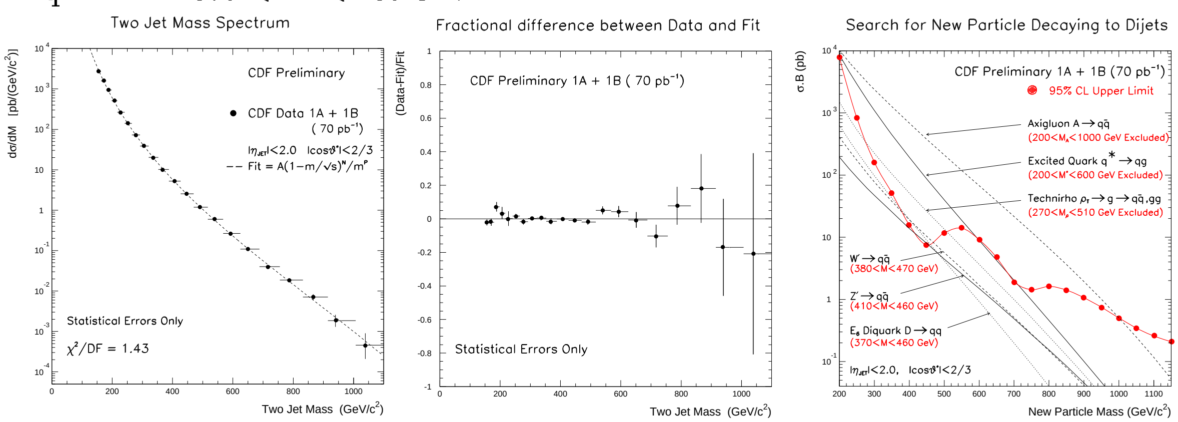

Figure 4: **a)** Dijet mass distribution and fit to a smooth parametrization (solid curve). Both jets are required to have pseudorapidity $|\eta| < 2.0$ and the dijet system satisfies $|cos\theta^*| < 2/3$. **b)** The fractional difference between the dijet mass distribution (points) and a smooth background fit (solid line). **c)** The upper limit in the cross section times branching ratio for new particles decaying to dijets (points) compared to theoretical predictions for axigluons, excited quarks, color octet technirhos, new gauge bosons W' and Z', and E_6 diquarks.

6. Search for New Particles Decaying to B-Tagged Dijets (CDF, Run Ia)

Requiring that the final jets are coming from Bottom-quarks might help rejecting the QCD background in certain cases (when couplings to heavy quarks are favored by the theory). This analysis requires the same kinematical cuts used in the plain dijet search plus B-tagging (secondary vertex found by the silicon vertex detector) at least in one of the two leading jets. The B-tagged dijet mass spectrum extends from 150 to 650 GeV (figure 5**a**) and is found to be a smoothly falling distribution within statistics. The highest mass double B-tagged event has a mass of 256 GeV.

The B-tagged dijet mass spectrum is used to search for mass resonances. A 95% CL upper limit on the cross section for new particles as a function of mass is obtained by fitting the data to a smooth background function plus a mass resonance. Narrow resonances that could be produced by a color octet technirho, a standard Z', or a topcolor Z' are searched for. The topcolor [11] model seeks to explain the mass of the top quark by introducing a new SU(3) and U(1) symmetry coupled to the third generation. Also broad resonances that are produced by topcolor octet gauge bosons are searched for: topgluons defined by case C in PRD49, 4454 (1994). This preliminary analysis excludes at 95% CL topgluons in the mass range: $200 < M < 550\ GeV$ for width = 0.11 M, $210 < M < 450\ GeV$ for width = 0.3 M, and $200 < M < 370\ GeV$ for width = 0.5 M. Preliminary excluded regions are shown in figure 5**b** in the width vs. mass and SU(3) mixing vs. mass plane.

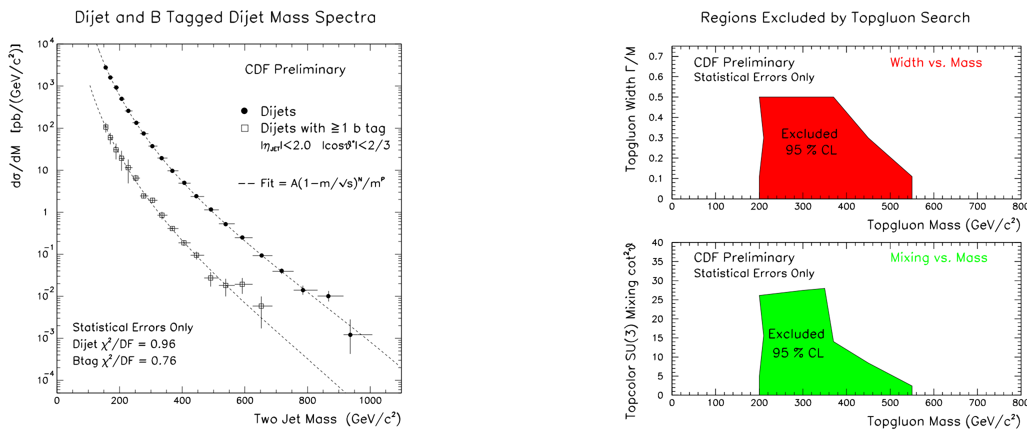

Figure 5: **a)** Dijet mass distribution without (upper points) and with b-tagging requirement (lower points) and fits to a smooth parametrization (solid curves). **b)** Excluded regions for topgluons.

7. Conclusions

The Tevatron, a $p\bar{p}$ collider at $\sqrt{s} = 1.8$, is currently providing the highest center of mass energies in the world and so is very well suited for searches of new phenomena. No new particle beyond the SM has been found so far by the CDF and D0 experiments.

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